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(54) **PERFORATING GUN WITH INTERNAL SHOCK MITIGATION**

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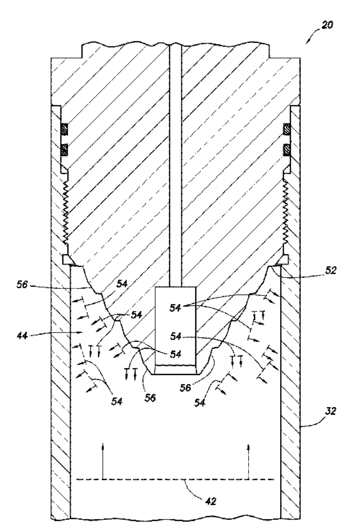
(57) **ABSTRACT**

A perforating gun can include at least one explosive component, and a shock mitigation device including a shock reflector which indirectly reflects a shock wave produced by detonation of the explosive component. Another perforating gun can include a gun housing, at least one explosive component, and a shock mitigation device in the gun housing. The shock mitigation device can include a shock attenuator which attenuates a shock wave produced by detonation of the explosive component. Yet another perforating gun can include a shock mitigation device with an explosive material which produces a shock wave that interacts with another shock wave produced by detonation of an explosive component in a gun housing.

9 Claims, 6 Drawing Sheets



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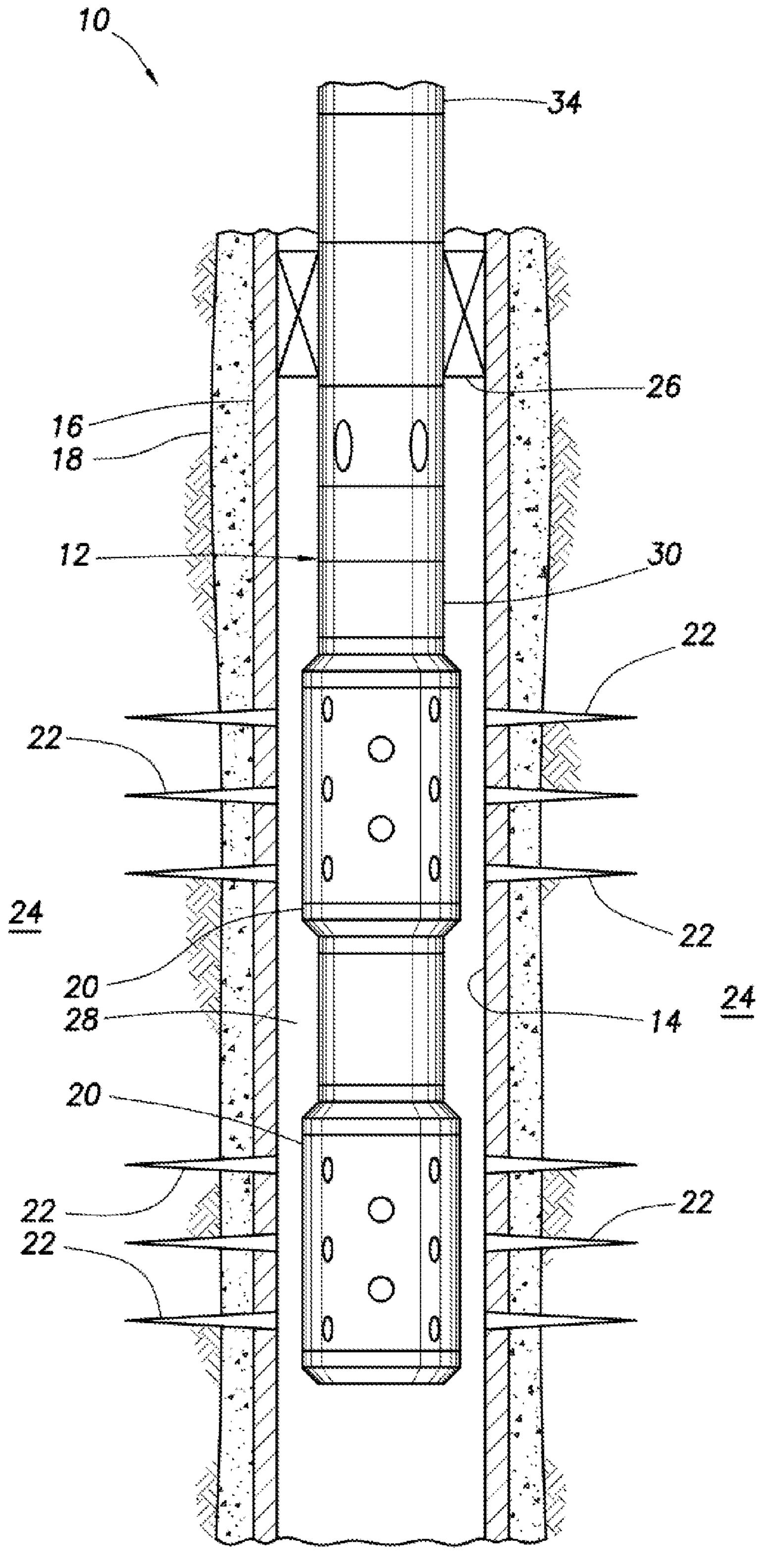

FIG. 1

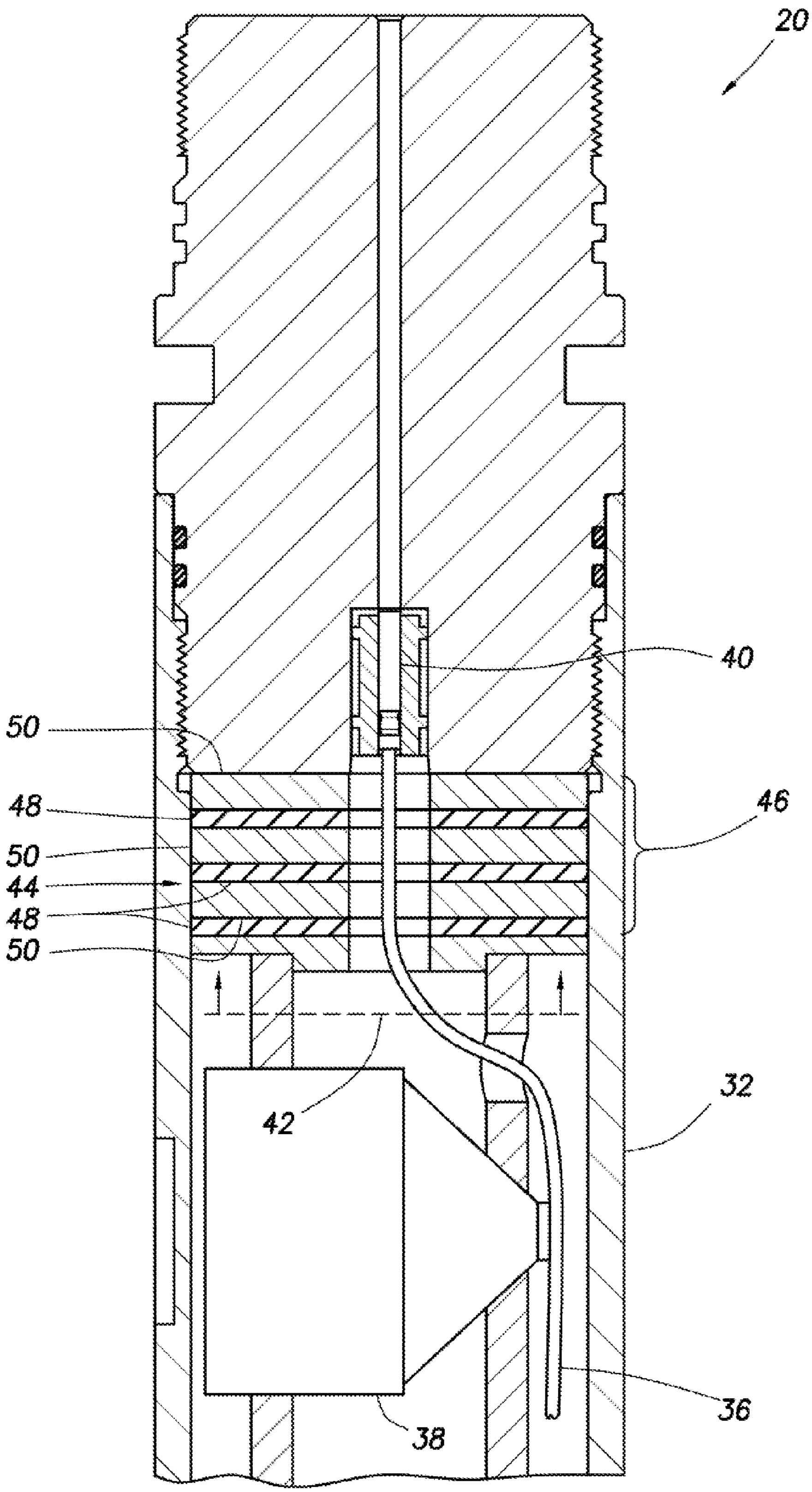

FIG.2

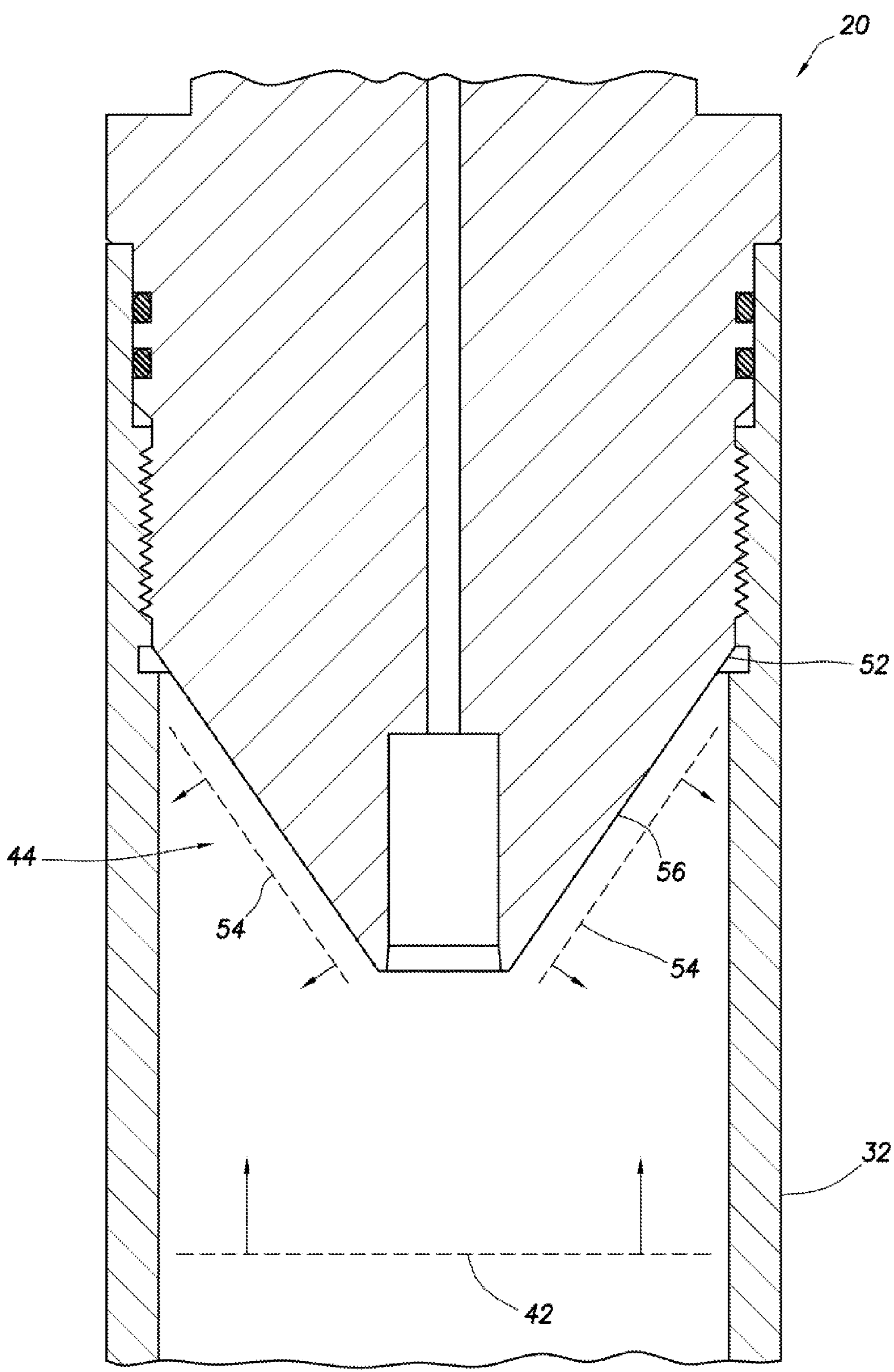

FIG.3

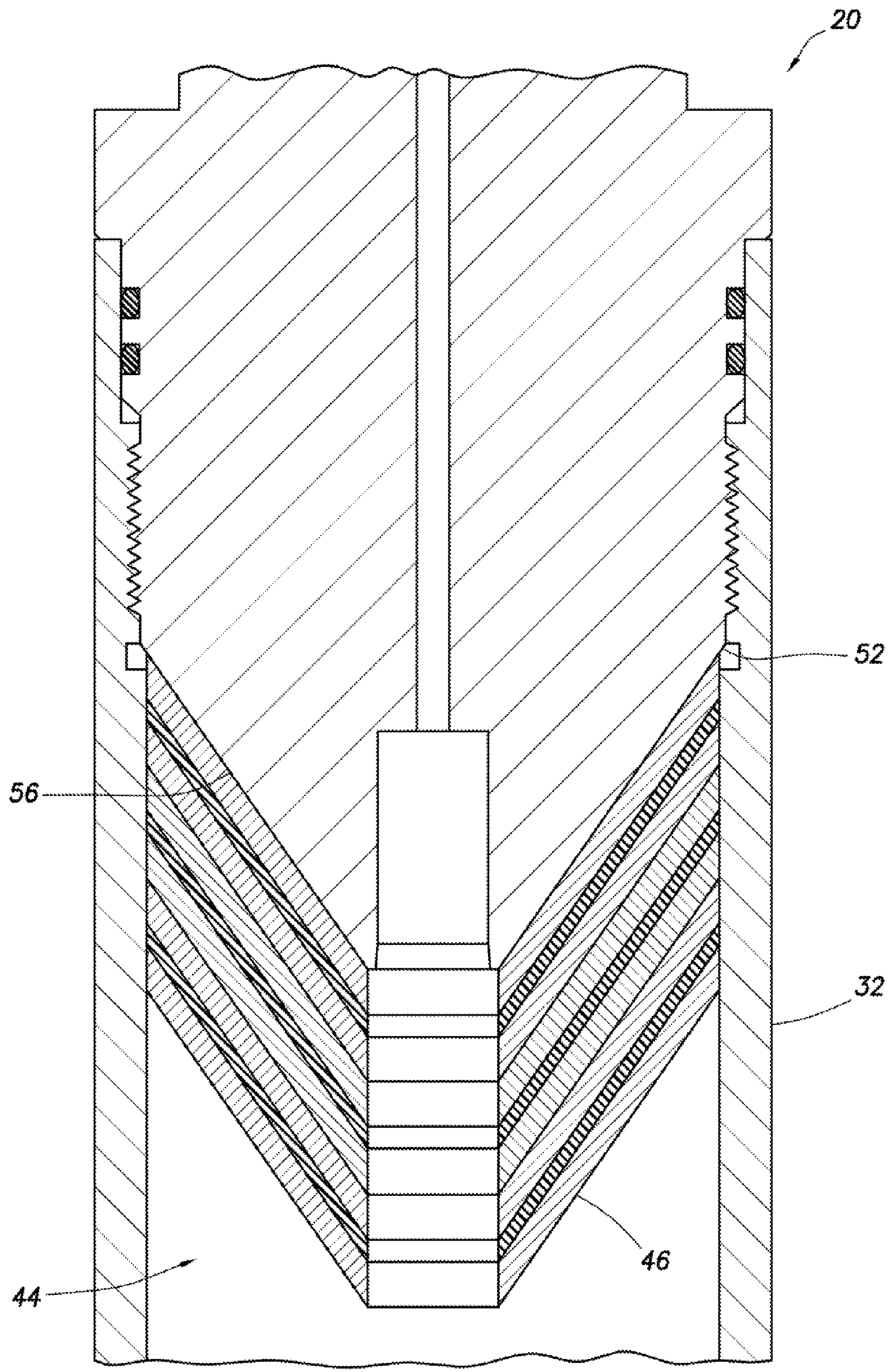

FIG. 4

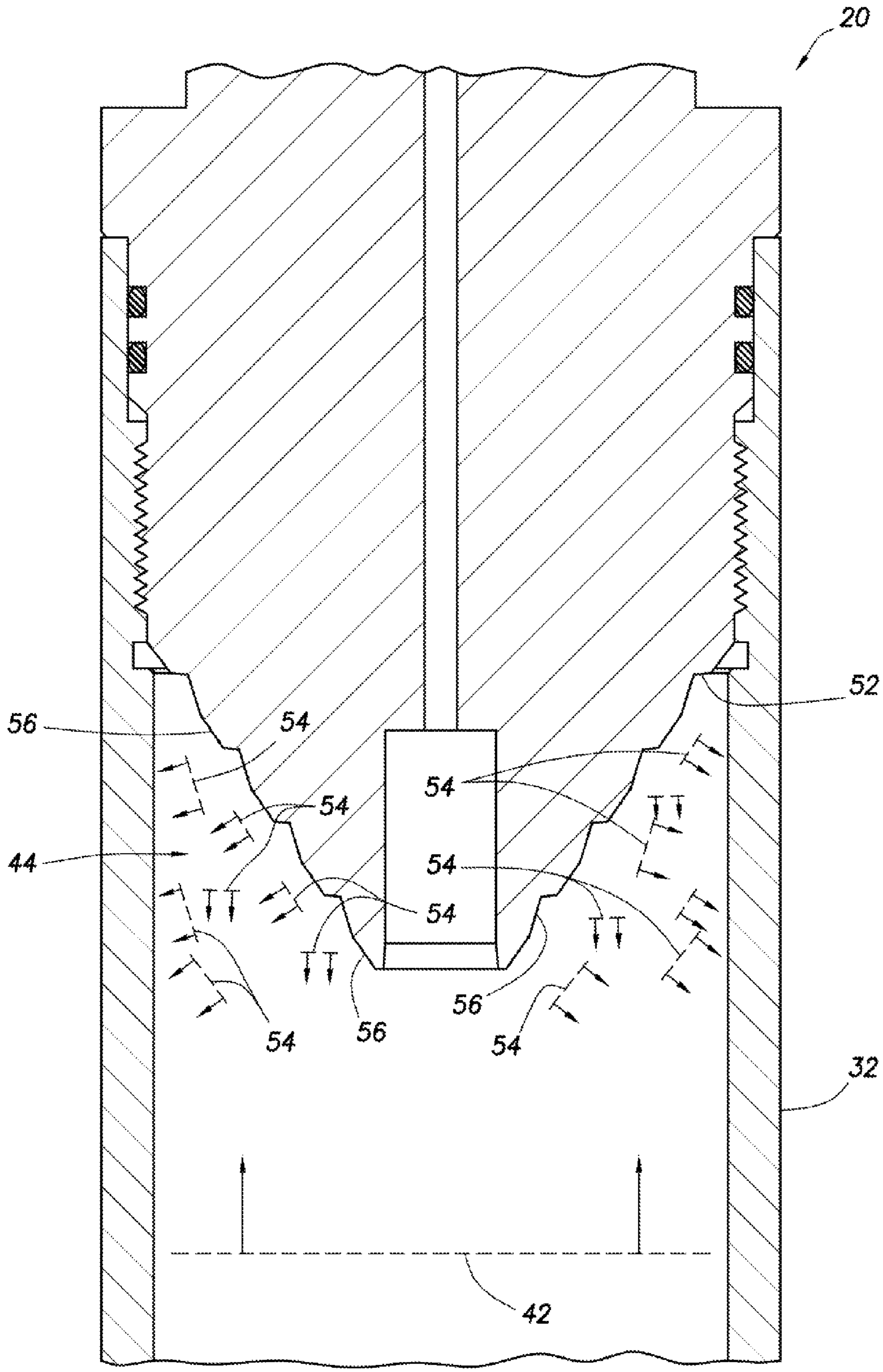

FIG.5

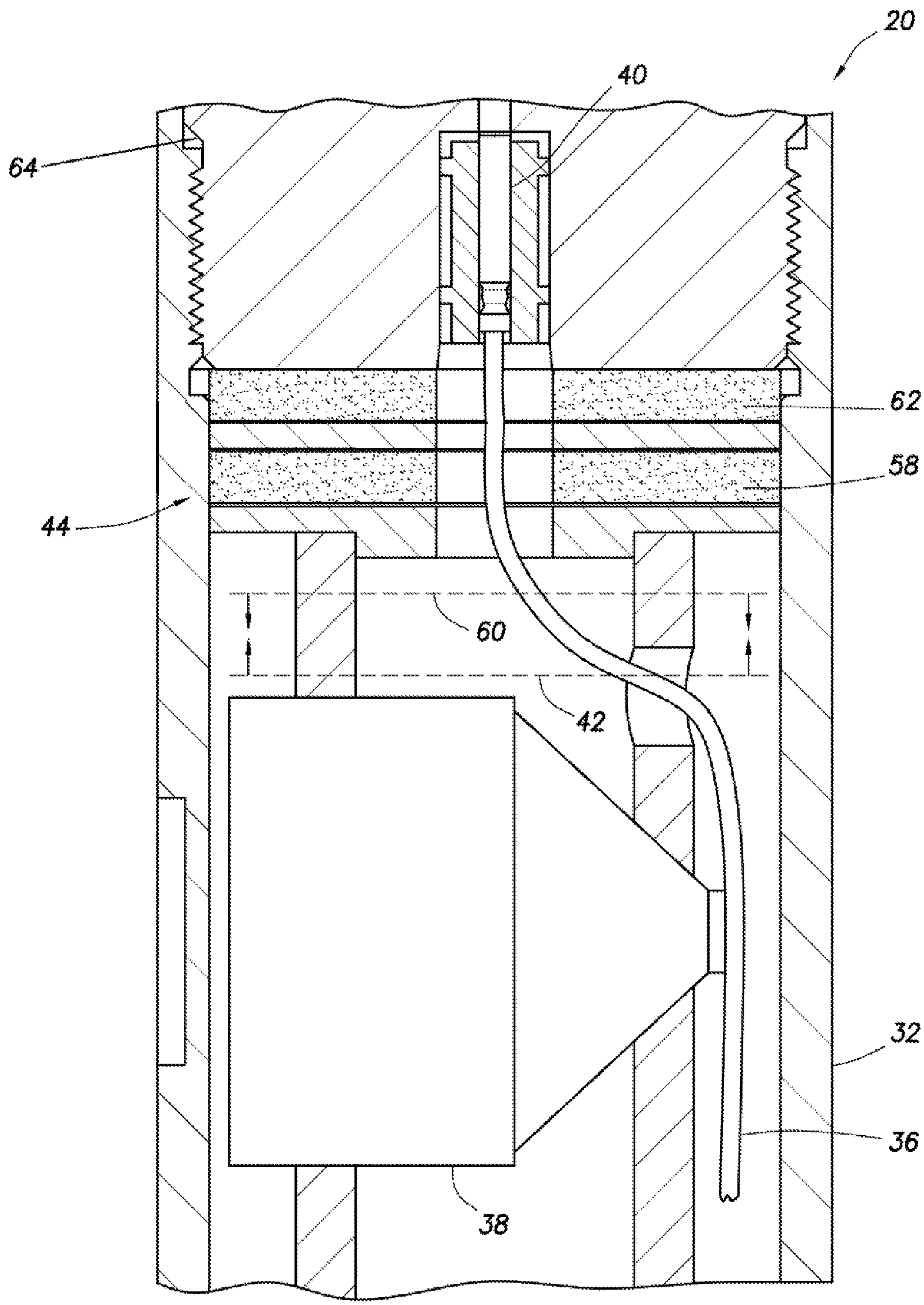

FIG. 6

PERFORATING GUN WITH INTERNAL SHOCK MITIGATION

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit under 35 USC §119 of the filing date of International Application Serial No. PCT/US11/49882 filed 31 Aug. 2011. The entire disclosure of this prior application is incorporated herein by this reference.

BACKGROUND

The present disclosure relates generally to equipment utilized and operations performed in conjunction with a subterranean well and, in an embodiment described herein, more particularly provides for mitigating shock produced by well perforating.

Shock absorbers have been used in the past to absorb shock produced by detonation of perforating guns in wells. Unfortunately, prior shock absorbers have had only very limited success. Therefore, it will be appreciated that improvements are needed in the art of mitigating shock produced by perforating strings.

SUMMARY

In carrying out the principles of this disclosure, a perforating gun is provided with improvements in the art. One example is described below in which a shock mitigation device in a perforating gun reflects shock produced by detonation of the perforating gun. Another example is described below in which the shock mitigation device attenuates the shock. Yet another example is described in which the device produces a shock wave that interacts with a shock wave produced by detonation of the perforating gun.

In one aspect, a perforating gun is provided to the art by this disclosure. In one example, the perforating gun can include at least one explosive component, and a shock mitigation device with a shock reflector which indirectly reflects a shock wave produced by detonation of the explosive component.

In another aspect, a perforating gun is described below which, in one example, can include a gun housing, at least one explosive component, and a shock mitigation device in the gun housing. The shock mitigation device includes a shock attenuator which attenuates a shock wave produced by detonation of the explosive component.

In yet another aspect, the disclosure below describes a perforating gun in which a shock mitigation device includes an explosive material which produces a shock wave that interacts with another shock wave produced by detonation of an explosive component in a gun housing.

These and other features, advantages and benefits will become apparent to one of ordinary skill in the art upon careful consideration of the detailed description of representative embodiments of the disclosure hereinbelow and the accompanying drawings, in which similar elements are indicated in the various figures using the same reference numbers.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a representative partially cross-sectional view of a well system and associated method which can embody principles of this disclosure.

FIG. **2** is a representative cross-sectional view of a perforating gun which may be used in the system and method of FIG. **1**, and which can embody principles of this disclosure.

FIGS. **3**-**6** are representative cross-sectional views of additional configurations of a shock mitigating device in the perforating gun.

DETAILED DESCRIPTION

Representatively illustrated in FIG. **1** is a system **10** for use with a well, and an associated method, which can embody principles of this disclosure. In the system **10**, a perforating string **12** is positioned in a wellbore **14** lined with casing **16** and cement **18**. Perforating guns **20** in the perforating string **12** are positioned opposite predetermined locations for forming perforations **22** through the casing **16** and cement **18**, and outward into an earth formation **24** surrounding the wellbore **14**.

The perforating string **12** is sealed and secured in the casing **16** by a packer **26**. The packer **26** seals off an annulus **28** formed radially between the tubular string **12** and the wellbore **14**. A tubular string **34** (such as a work string, a production tubing string, an injection string, etc.) may be interconnected above the packer **26**.

A firing head **30** is used to initiate firing or detonation of the perforating guns **20** (e.g., in response to a mechanical, hydraulic, electrical, optical or other type of signal, passage of time, etc.), when it is desired to form the perforations **22**. Although the firing head **30** is depicted in FIG. **1** as being connected above the perforating guns **20**, one or more firing heads may be interconnected in the perforating string **12** at any location, with the location(s) preferably being connected to the perforating guns by a detonation train.

At this point, it should be noted that the well system **10** of FIG. **1** is merely one example of an unlimited variety of different well systems which can embody principles of this disclosure. Thus, the scope of this disclosure is not limited at all to the details of the well system **10**, its associated methods, the perforating string **12**, etc. described herein or depicted in the drawings.

For example, it is not necessary for the wellbore **14** to be vertical, for there to be two of the perforating guns **20**, or for the firing head **30** to be positioned between the perforating guns and the packer **26**, etc. Instead, the well system **10** configuration of FIG. **1** is intended merely to illustrate how the principles of this disclosure may be applied to an example perforating string **12**, in order to mitigate the effects of a perforating event. These principles can be applied to many other examples of well systems and perforating strings, while remaining within the scope of this disclosure.

It will be appreciated by those skilled in the art that detonation of the perforating guns **20** produces shock which can damage or unset the packer **26**, or damage the tubular string **34**, firing head **30** or other components of the perforating string **12**. In the past, it has been common practice to attempt to absorb shock produced by detonation of perforating guns, using shock absorbers interconnected between components of perforating strings.

In contrast, the present inventors have conceived unique ways of mitigating shock that do not involve the use of shock absorbers between components of a perforating string. Of course, shock absorbers could be used in combination with the concepts described herein, while remaining within the scope of this disclosure.

Referring additionally now to FIG. **2**, an enlarged scale cross-sectional view of a portion of one of the perforating guns **20** is representatively illustrated. This perforating gun **20** example may be used in the well system **10** and method described above, or it may be used in other well systems and methods.

As depicted in FIG. **2**, the perforating gun **20** includes a generally tubular gun housing **32** and explosive components (such as detonating cord **36**, perforating charges **38**, detonation boosters **40**, etc.) in the gun housing. When the explosive components are detonated (e.g., to form the perforations **22**), shock waves **42** are produced. For clarity of illustration, only one of the shock waves **42** is representatively depicted as a dashed line in FIG. **2**.

To mitigate transmission of the shock wave **42** to other components of a perforating string, the perforating gun **20** also includes a shock mitigating device **44**. In this example, the shock mitigating device **44** is enclosed within the gun housing **32** and functions to mitigate shock prior to the shock reaching any other components of the perforating string. One advantage of this arrangement is that such shock mitigating devices **44** can be used in each of multiple perforating guns in a perforating string, so that the shock produced by each perforating gun is internally mitigated.

In the FIG. **2** example, the device **44** includes a shock attenuator **46** which attenuates the shock wave **42**. The attenuator **46** includes alternating layers of resilient material **48** (e.g., elastomers, rubber, fluoro-elastomers, etc.) and non-resilient material **50** (e.g., soft metals such as aluminum, bronze, etc., crushable materials, etc.).

The attenuator **46** desirably decreases the amplitude of the shock wave **42**. However, other types of shock attenuators may be used, if desired.

Preferably, the attenuator **46** provides sharply varying acoustic impendances (e.g., due to the layers of resilient and non-resilient materials **48**, **50**). For example, density, modulus, and/or other characteristics of materials can affect their acoustic impendances. By varying these characteristics from one layer to another, corresponding varying acoustic impendances are obtained (e.g., alternating layers of metal and poly-ether-ether-ketone, etc.). Thus, the attenuator **46** can be constructed without alternating layers of materials **48**, **50** which are necessarily resilient and non-resilient, but which have substantially different acoustic impedances.

Referring additionally now to FIG. **3**, the perforating gun **20**, with another configuration of the shock mitigating device **44**, is representatively illustrated. The explosive components are not depicted in FIG. **3** for clarity of illustration.

In this example, the shock mitigating device **44** includes a shock reflector **52** which reflects the shock wave **42** produced by detonation of the explosive components. Preferably, the reflected shock wave(s) **54** are not reflected directly back in a direction opposite to the direction of the shock wave **42**. Instead, the shock wave **42** is reflected outward by a convex generally conical surface **56** of the reflector **52**. In other examples, the surface **56** is not necessarily convex or conical, but preferably the surface does indirectly reflect the shock wave **42**.

Referring additionally now to FIG. **4**, another configuration of the shock mitigating device **44** is representatively illustrated. In this example, the shock mitigating device **44** includes both the reflector **52** of FIG. **3** and the attenuator **46** of FIG. **2** (albeit formed into a generally conical shape).

This demonstrates that the features of the various examples described herein can be combined as desired, for example, to obtain benefits of those combined features. In the FIG. **4** example, the shock wave **42** will be attenuated by the attenuator **46** prior to being reflected by the surface **56** of the reflector **52**.

Referring additionally now to FIG. **5**, another configuration of the shock mitigating device **44** is representatively illustrated. In this example, the surface **56** of the reflector **52** comprises multiple individual surfaces, instead of a single conical surface, although the surfaces are still in a generally conical arrangement. A shock attenuator **46** may be used with the reflector **52** (similar to the combined attenuator **46** and reflector **52** in the device **44** configuration of FIG. **4**), if desired.

The surfaces **56** cause many smaller (as compared to the reflected shock wave in the FIG. **3** configuration) shock waves **54** to be reflected in various directions. Preferably, the reflected shock waves **54** are directed generally outward toward the gun housing **32**, and are not reflected directly back in the opposite direction of the shock wave **42**. Furthermore, it is preferable that the many reflected shock waves **54** interfere with each other and at least partially cancel or attenuate one another.

For example, the impact of the shock wavefront from the blast can be spread over time to reduce peak amplitudes of shock in the steel tools of the perforating string **12**. The various incidence angles can provide a reduction in energy transfer from the fluid to the steel as more of the wave is reflected.

There is a distinction between the objective of reducing the initial response (and peak stress) due to the incoming shock wave, and reducing the multitude of reflections in the fluid or the structure which result in repeated peak stresses over some time.

The reflected waves in the fluid can be dispersed or scattered in timing and direction to reduce reflected waves in the fluid. The angled faces of the steel can also break up the internal reflections of the waves within the steel part. This is in sharp contrast to conventional perforating guns with a uniform flat surface impacted at 90 degrees by an incoming wave, allowing for maximum transmission of energy and peak amplitudes in a steel gun housing.

In practice, exactly which direction the waves are reflected (by the angle(s) on the surface(s) **56**) should be carefully considered to avoid creating a local stress problem on the gun housing **32** wall. This is relevant to all of the examples described above.

Thus, it will be appreciated that the shock mitigation device **44** may mitigate shock by reflecting, absorbing, breaking-up, scattering and/or dispersing the shock wave **42**.

Referring additionally now to FIG. **6**, yet another configuration of the shock mitigating device **44** is representatively illustrated. In this example, the device **44** includes a material **58** which produces a shock wave **60** that is oppositely directed relative to the shock wave **42** produced by detonation of the explosive components of the perforating gun **20**, and is preferably timed to be at least partially out of phase with the shock wave **42**.

The material **58** could be, for example, an explosive sheet material. The material **58** may be detonated in response to detonation of any of the other explosive components (such as, the detonating cord **36**, perforating charge **38** or detonation booster **40**, etc.). Alternatively, the material **58** could be detonated a certain amount of time before or after the other explosive components are detonated.

Preferably, the shock wave **60** produced by detonation of the material **58** at least partially "cancels" the shock wave **42**, thereby attenuating the shock wave. A sum of the shock waves **42**, **60** is preferably less than an amplitude of either of the shock waves.

A shock attenuator **46** may be used with the FIG. **6** example. The shock attenuator **46** could include the materials **48**, **50** described above, or in other examples, the shock attenuator could include a dispersive media **62** (such as sand or glass beads, etc.) to dissipate shock between a fluid interface and a structure (such as a connector body **64**). For example, the dispersive media could be positioned between a steel plate and the connector body **64**.

In any of the examples described above, the device **44** can be configured so that it has a desired amount of shock mitigation. For example, the amount of explosive material **58** or the timing of the detonation in the FIG. **6** configuration can be changed as desired to produce the shock wave **60** having certain characteristics. As another example, the compliance, density, thickness, number and resilience of the layers of materials **48**, **50** in the configurations of FIGS. **2** & **4** can be varied to produce corresponding variations in shock attenuation.

This feature (the ability to vary the amount of internal shock mitigation) can be used to "tune" the overall perforating string **12**, so that shock effects on the perforating string are mitigated. Suitable methods of accomplishing this result are described in International Application serial nos. PCT/US10/61104 (filed 17 Dec. 2010), PCT/US11/34690 (filed 30 Apr. 2011), and PCT/US11/46955 (filed 8 Aug. 2011). The entire disclosures of these prior applications are incorporated herein by this reference.

The examples of the shock mitigating device **44** described above demonstrate that a wide variety of different configurations are possible, while remaining within the scope of this disclosure. Accordingly, the principles of this disclosure are not limited in any manner to the details of the device **44** examples described above or depicted in the drawings.

It may now be fully appreciated that this disclosure provides several advancements to the art of mitigating shock effects in subterranean wells. Various examples of shock mitigating devices **44** described above can effectively prevent or at least reduce transmission of shock to other components of the perforating string **12**.

In one aspect, the above disclosure provides to the art a perforating gun **20**. In one example, the perforating gun **20** can include at least one explosive component (such as, the detonating cord **36**, perforating charge **38** or detonation booster **40**, etc.), and a shock mitigation device **44** including a shock reflector **52** which indirectly reflects a shock wave **42** produced by detonation of the explosive component.

The shock mitigation device **44** may close off an end of a gun housing **32** containing the explosive component.

At least one surface **56** on the shock reflector **52** may indirectly reflect the shock wave **42**. The surface **56** can reflect the shock wave **42** toward a gun housing **32** containing the explosive component. The surface **56** may be generally conical-shaped.

The surface **56** may comprise multiple surfaces which reflect the shock wave **42** as respective multiple reflected shock waves **54**. The reflected shock waves **54** may interfere with each other.

The shock mitigation device **44** can include a shock attenuator **46** which attenuates the shock wave **42**. The shock reflector **52** may reflect the attenuated shock wave **42**. The shock attenuator **46** may comprise layers of resilient and non-resilient materials **48**, **50**. Additional examples of resilient structures include mechanical springs, etc. Additional examples of non-resilient materials include crushable structures, such as honeycomb or other celled structure, etc.

The shock attenuator **46** may comprises variations in acoustic impedance. The shock attenuator **46** may comprise a dispersive media **62**.

Also described above is a perforating gun **20** which, in one example, can include a gun housing **32**, at least one explosive component (such as, the detonating cord **36**, perforating charge **38** or detonation booster **40**, etc.), and a shock mitigation device **44** in the gun housing **32**. The shock mitigation device **44** may include a shock attenuator **46** which attenuates a shock wave **42** produced by detonation of the explosive component.

The shock mitigation device **44** may reflect the attenuated shock wave **42**, directly or indirectly. The shock mitigation device **44** may mitigate shock by reflecting, absorbing, breaking-up, scattering and/or dispersing a shock wave **42**.

This disclosure also describes a perforating gun **20** which, in one example, includes a gun housing, at least one explosive component (such as, the detonating cord **36**, perforating charge **38** or detonation booster **40**, etc.), and a shock mitigation device **44** in the gun housing **32**, the shock mitigation device **44** including an explosive material **58** which produces a first shock wave **60** that interacts with a second shock wave **42** produced by detonation of the explosive component.

The first shock wave **60** may at least partially counteract or cancel the second shock wave **42**. A sum of the first and second shock waves **42**, **60** can have an amplitude which is less than that of each of the first and second shock waves **42**, **60**.

The explosive material **58** may detonate a predetermined amount of time before or after the explosive component detonates. The explosive component and the explosive material **58** may detonate substantially simultaneously.

The first shock wave **60** may be produced in response to impingement of the second shock wave **42** on the shock mitigation device **44**. The first shock wave **60** preferably propagates in a direction opposite to a direction of propagation of the second shock wave **42**.

It is to be understood that the various embodiments of this disclosure described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., and in various configurations, without departing from the principles of this disclosure. The embodiments are described merely as examples of useful applications of the principles of the disclosure, which is not limited to any specific details of these embodiments.

In the above description of the representative examples, directional terms (such as "above," "below," "upper," "lower," etc.) are used for convenience in referring to the accompanying drawings. However, it should be clearly understood that the scope of this disclosure is not limited to any particular directions described herein.

Of course, a person skilled in the art would, upon a careful consideration of the above description of representative embodiments of the disclosure, readily appreciate that many modifications, additions, substitutions, deletions, and other changes may be made to the specific embodiments, and such changes are contemplated by the principles of this disclosure. Accordingly, the foregoing detailed description is to be clearly understood as being given by way of illustration and example only, the spirit and scope of the invention being limited solely by the appended claims and their equivalents.

What is claimed is:

1. A perforating gun, comprising:

at least one explosive component; and

a shock mitigation device including a shock reflector which indirectly reflects a shock wave in a fluid within the perforating gun, the shock wave produced by detonation of the explosive component, wherein the shock reflector comprises multiple tiered shock reflecting surfaces having different diameters, wherein the shock reflecting surfaces are generally conical-shaped, wherein the shock reflecting surfaces are convex relative to the explosive component, and wherein at least two of the shock reflecting surfaces have different incidence angles, whereby the shock wave is reflected as respective multiple reflected shock waves in different directions, thereby breaking up the shock wave and reducing an energy transfer from the fluid to an internal surface of the perforating gun.

2. The perforating gun of claim **1**, wherein the shock mitigation device closes off an end of a gun housing containing the explosive component.

3. The perforating gun of claim **1**, wherein the shock reflector reflects the shock wave toward a gun housing.

4. The perforating gun of claim **1**, wherein the respective multiple reflected shock waves interfere with each other.

5. The perforating gun of claim **1**, wherein the shock mitigation device comprises a shock attenuator which attenuates the shock wave.

6. The perforating gun of claim **5**, wherein the shock reflector reflects the attenuated shock wave.

7. The perforating gun of claim **5**, wherein the shock attenuator comprises layers of resilient and non-resilient materials.

8. The perforating gun of claim **5**, wherein the shock attenuator comprises variations in acoustic impedance.

9. The perforating gun of claim **5**, wherein the shock attenuator comprises a dispersive media.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,091,152 B2
APPLICATION NO. : 13/493327
DATED : July 28, 2015
INVENTOR(S) : Rodgers et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title page of the patent, item (30) the following priority data should be added:

Foreign Application Priority Data:

Aug. 31, 2011 (WO) PCT/US2011/049882

Signed and Sealed this
Twenty-sixth Day of April, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office